Planck Clusters & Neutrinos

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Government sponsorship acknowledged

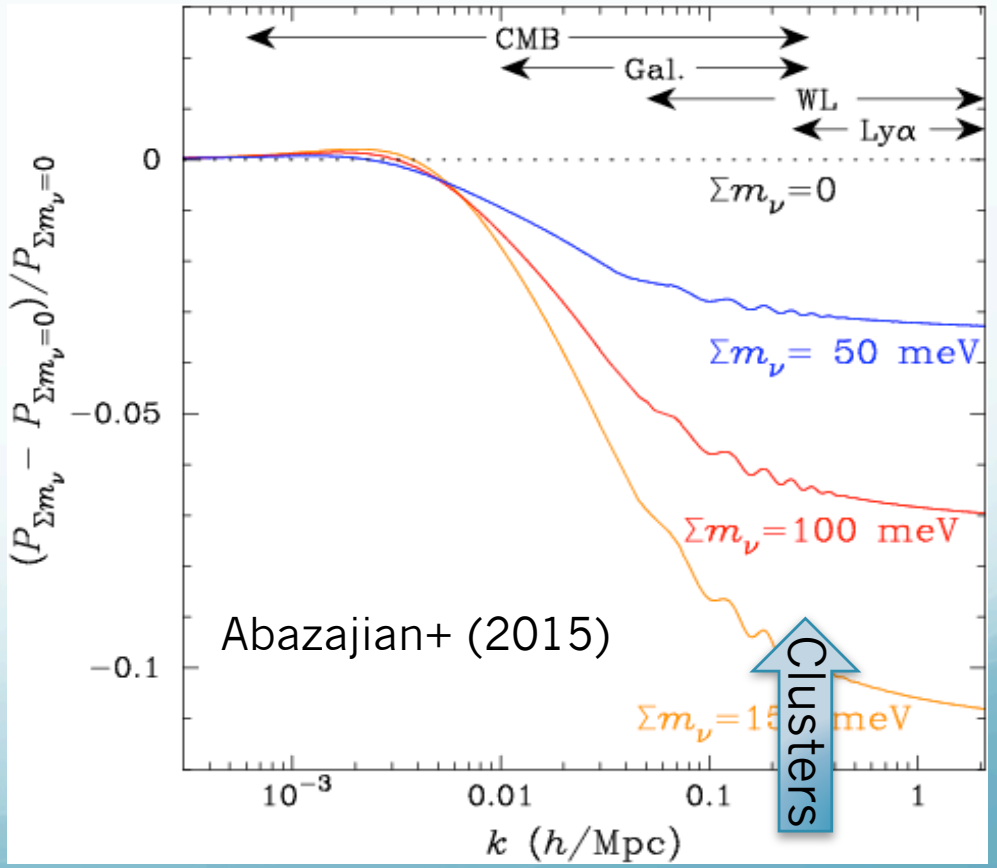
Cluster Cosmology

- Massive halo abundance **very** sensitive to amplitude of density perturbations (**Gaussian mass function**)

$$\sigma_8(z) = D_{\rm g}(z)\sigma_8$$

Cosmology: **neutrinos**

$$M_8 = \frac{4\pi}{3}\rho_{\rm m}R_8^3$$
$$= (6\times10^{14}\,M_\odot)\Omega_{\rm m}h^{-1}$$



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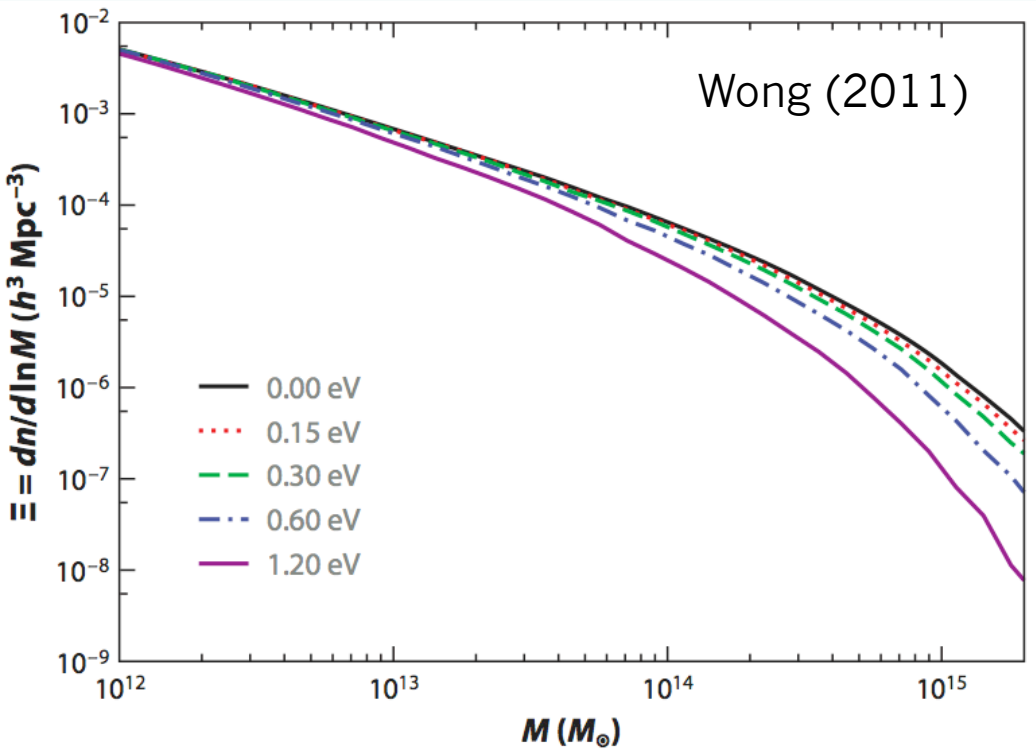
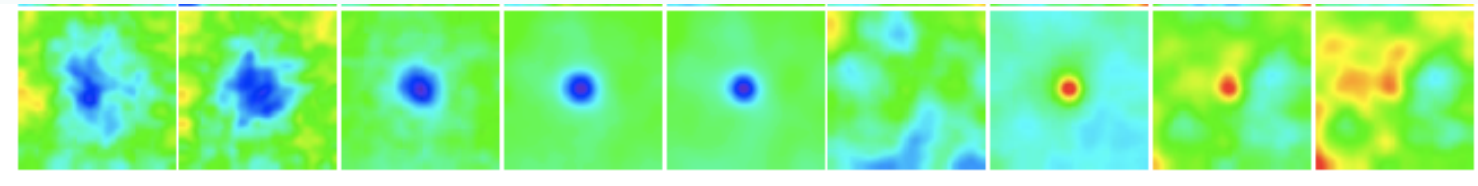


Planck Cluster Cosmology

J.G. Bartlett

Berkeley 2016

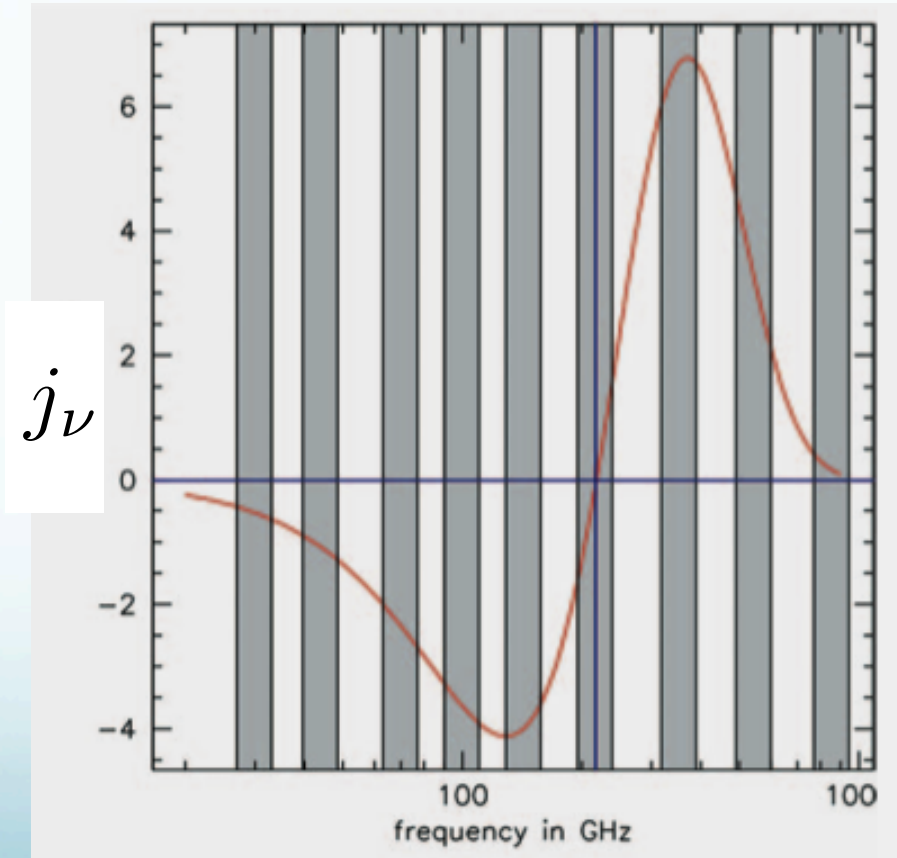
Planck SZ Clusters



Planck sees clusters through the thermal Sunyaev-Zeldovich (SZ) effect

$$\Delta i_\nu(\hat{n}) = y(\hat{n}) j_\nu$$

$$y = \int_{\rm los} dl \, \frac{kT_{\rm e}}{m_{\rm e}c^2} n_{\rm e} \sigma_{\rm T}$$

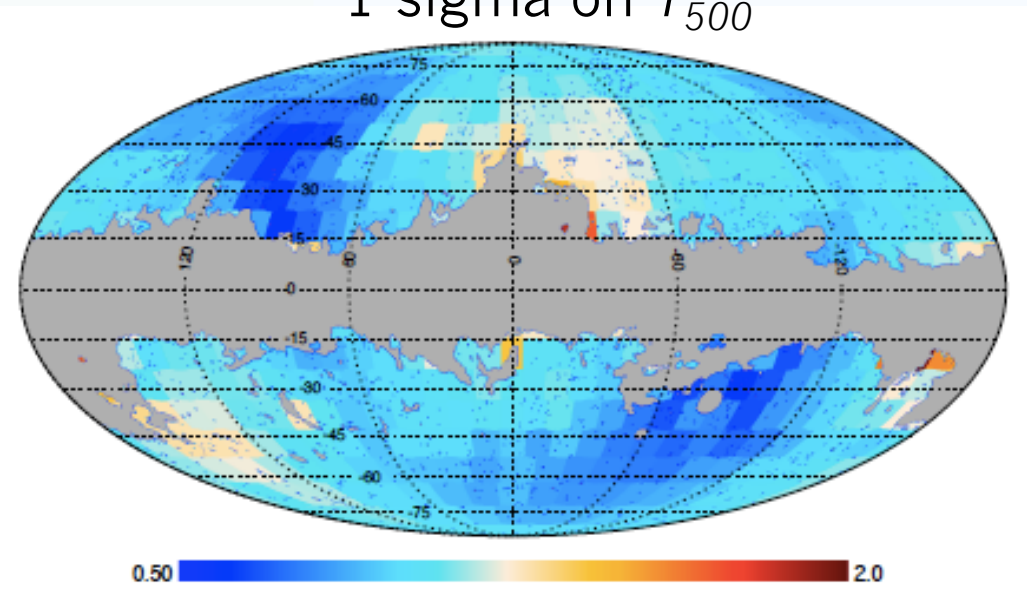


We detect clusters with a multi-frequency matched filter (Melin et al. 2006)

$$Y = \int d\Omega \, y(\hat{n})$$

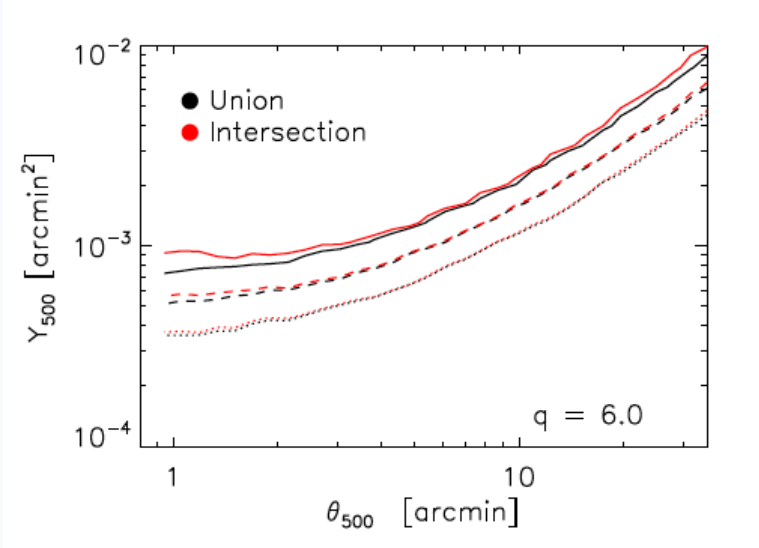
Planck Cosmology Sample

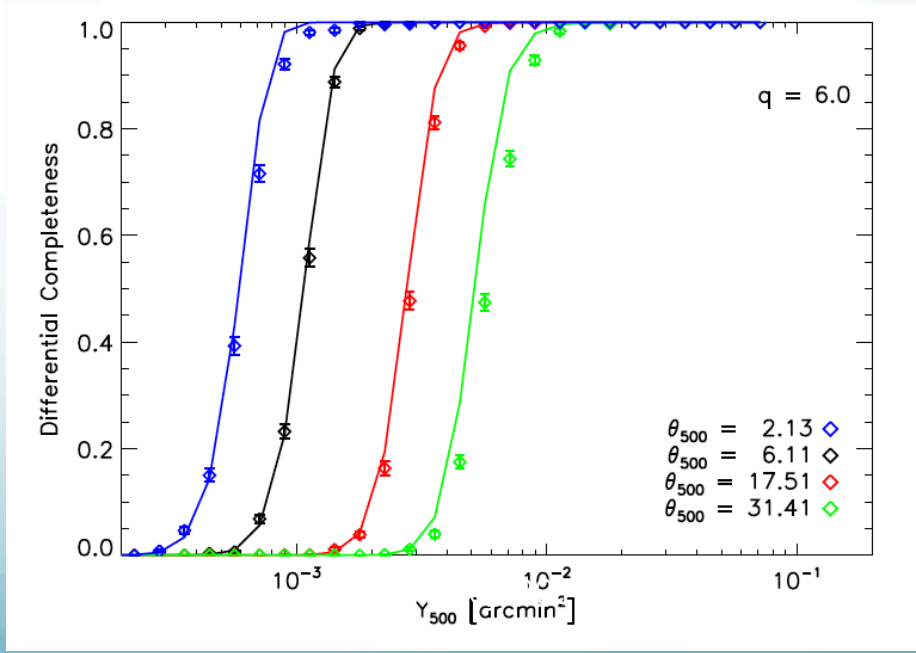
Survey depth at six-arcmin scale
1 sigma on Y_{500}



(0.5–2) x 2.2×10^{-4} arcmin^2

Planck Collaboration XXVII (2015)

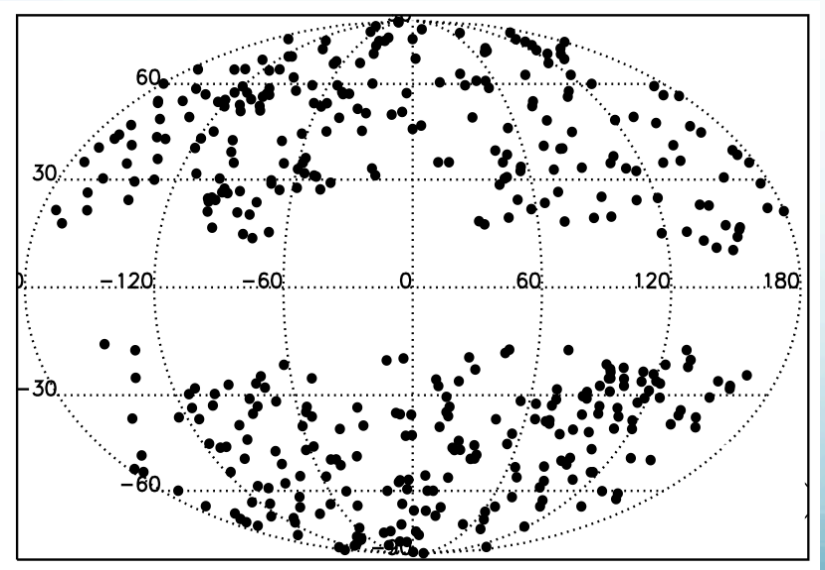


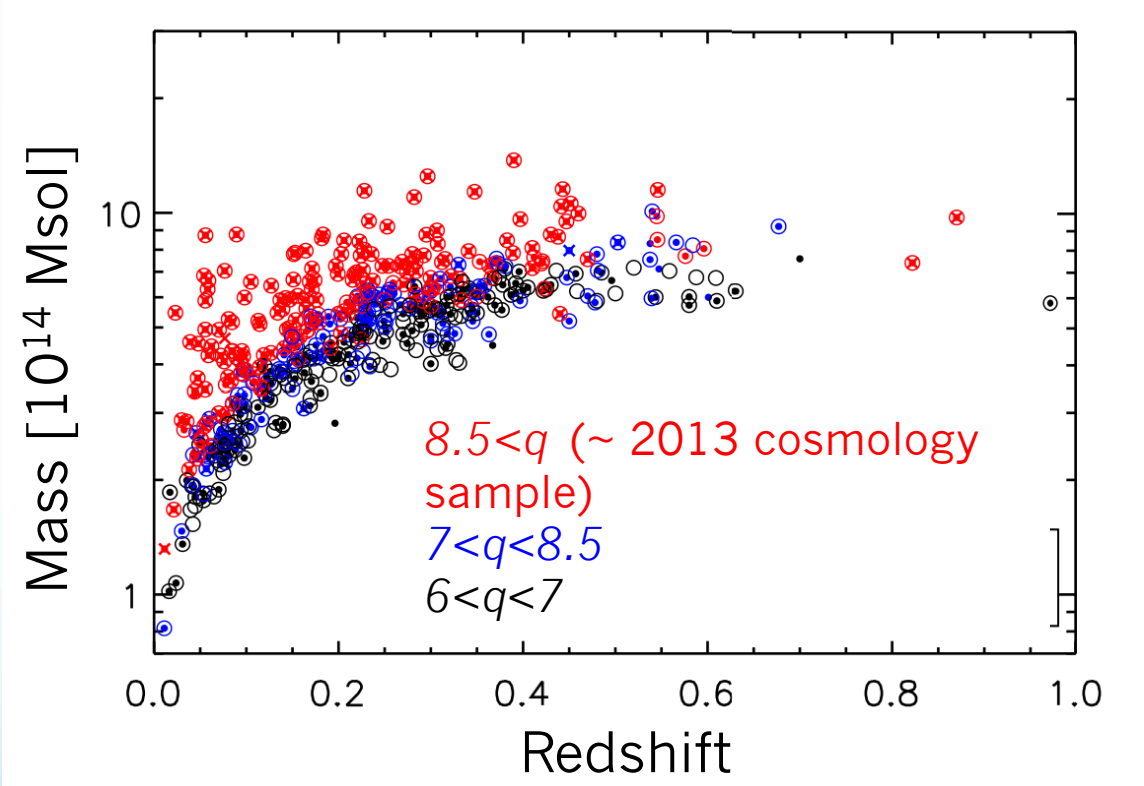


S/N=*q* > 6
439 clusters (up from 189)

Planck 2015 Cluster Catalog

- Full PSZ2 catalog
  - 1653 sources (up from 1227 in PSZ1)
- Cosmology sample
  - S/N=q > 6
  - 439 clusters (up from 189)





Planck Cluster Cosmology

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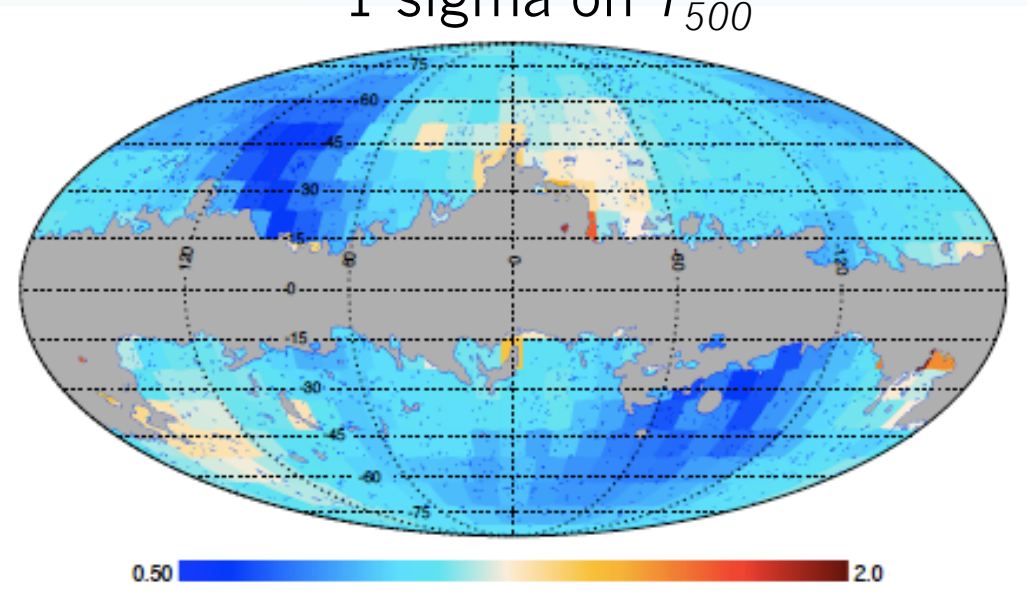


(0.5–2) x 2.2×10^{-4} arcmin^2

- Cluster counts are sensitive to cosmological parameters:

$$\sigma_8 \quad \Omega_{\rm m} \quad (H_0)$$

- Need scaling relation to relate observed signal to cluster mass

$$\bar{Y}_{500} \propto (M^X_{500})^\alpha \propto [(1-b)M_{500}]^\alpha$$

Hydrostatic mass from X-rays (XMM)

True cluster mass

- Parameter *b* = "Hydrostatic mass bias": simulations suggest b=0.2, but not all
- b really accounts for **all** sources of difference between true mass and hydrostatic mass

Mass-Observable Relation

$$P[Y_{500}|\bar{Y}_{500}, \sigma_{\ln Y}]$$

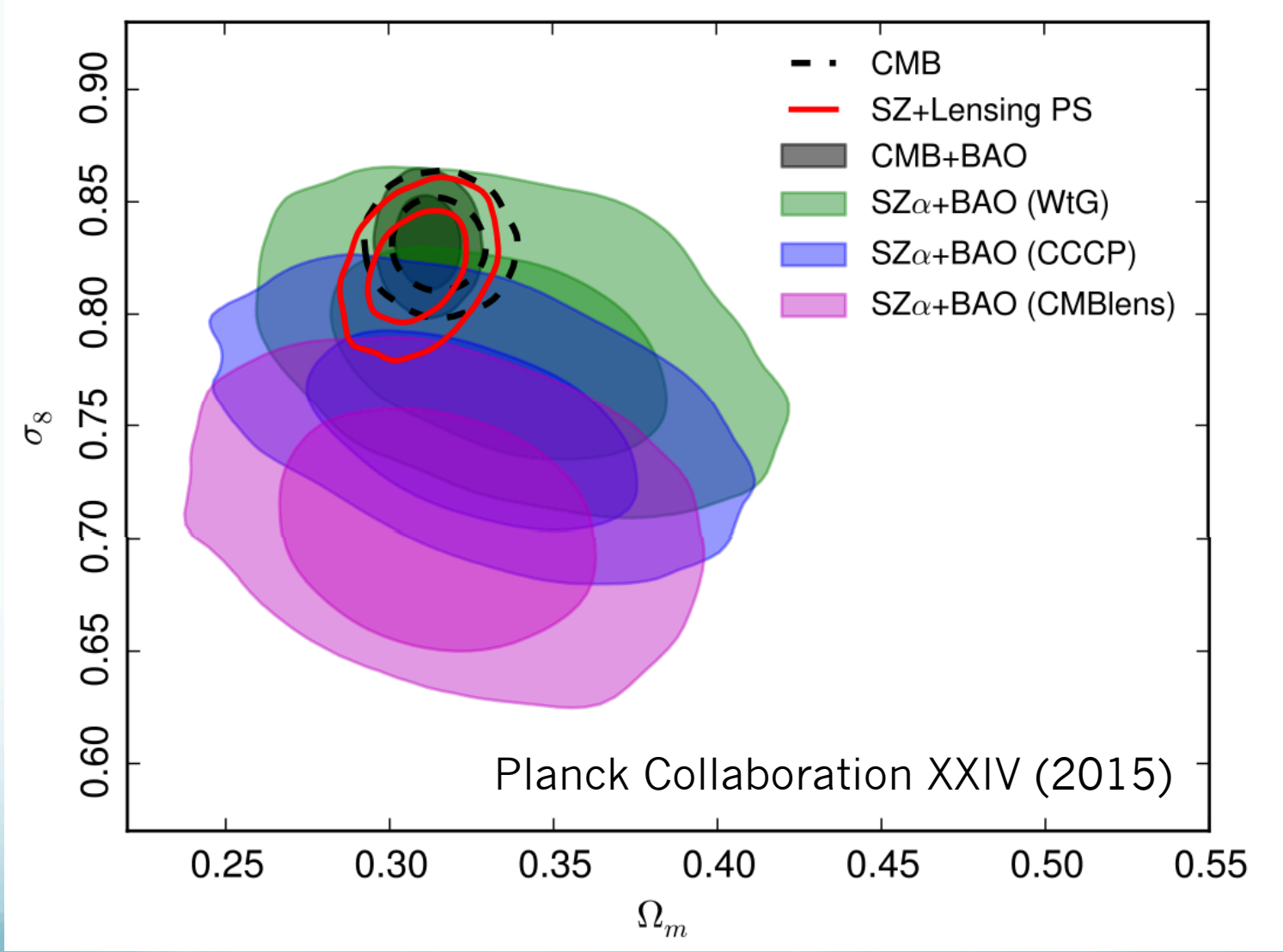
Ln-Normal distribution

$$\bar{Y}_{500} \propto (M^X_{500})^\alpha \propto [(1-b)M_{500}]^\alpha$$

$$\sigma_{\ln Y} = 0.173 \pm 0.02$$

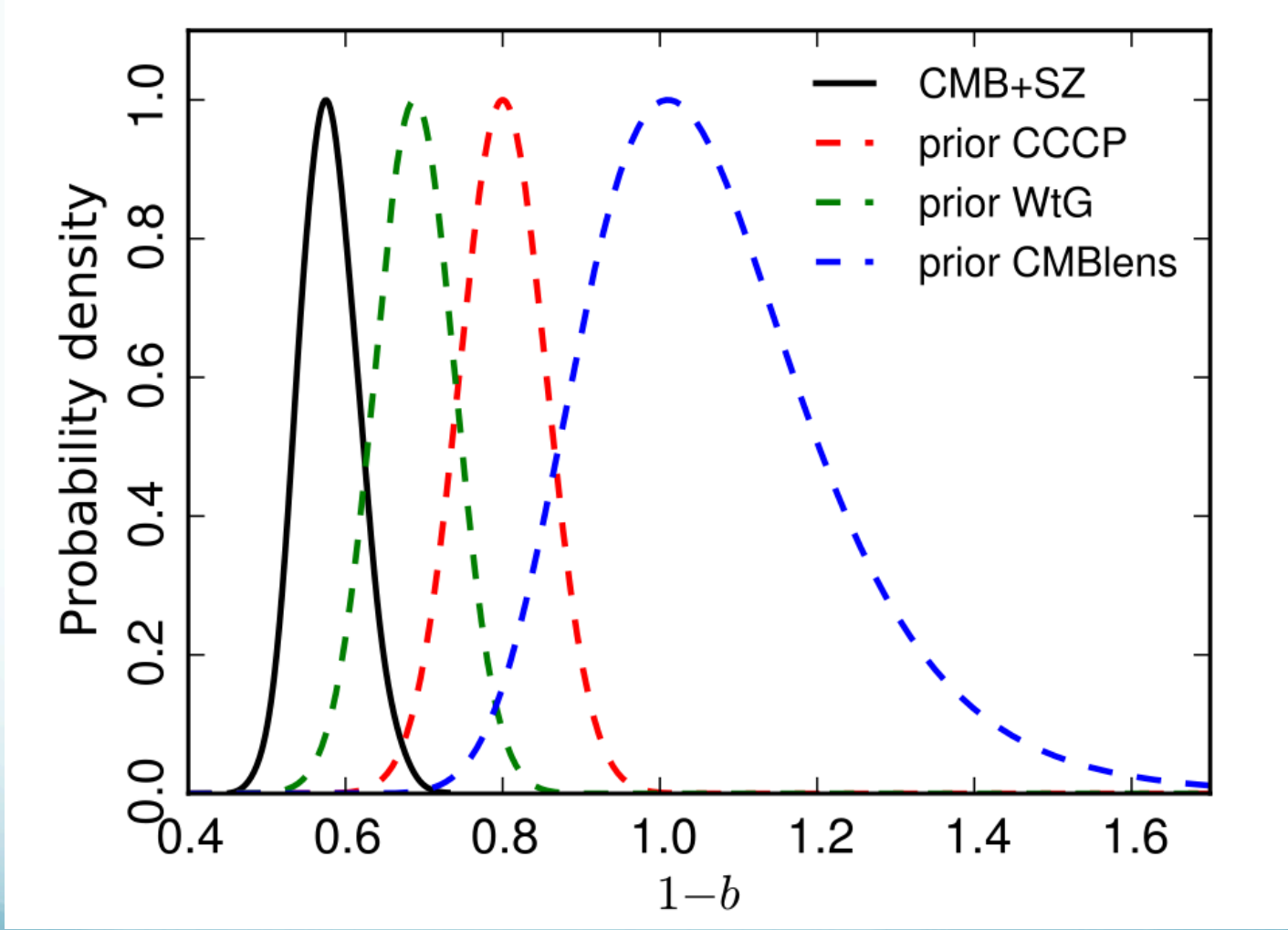
- Cluster-galaxy lensing
  - WtG von der Linden (2014): *(1-b) =0.688 ± 0.072*
    22 *Planck* clusters from the 2013 cosmology sample
  - CCCP Hoekstra et al. (2015): *(1-b)=0.78 ± 0.07* (stat) *± 0.06* (sys)
    20 *Planck* clusters from the 2013 cosmology sample
- Cluster-CMB lensing: Melin & Bartlett (2015)
  - *1/(1-b) = 0.99 ± 0.19* Full 2015 cosmology sample: 439 clusters

Planck Clusters 2015



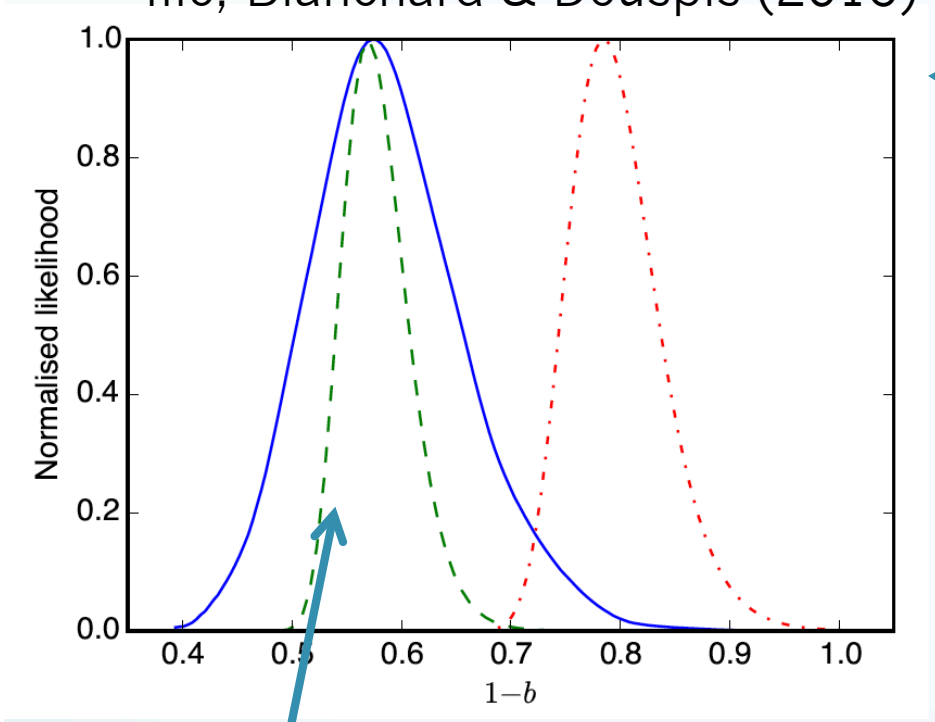
Mass Bias

Planck Collaboration XXIV (2015)



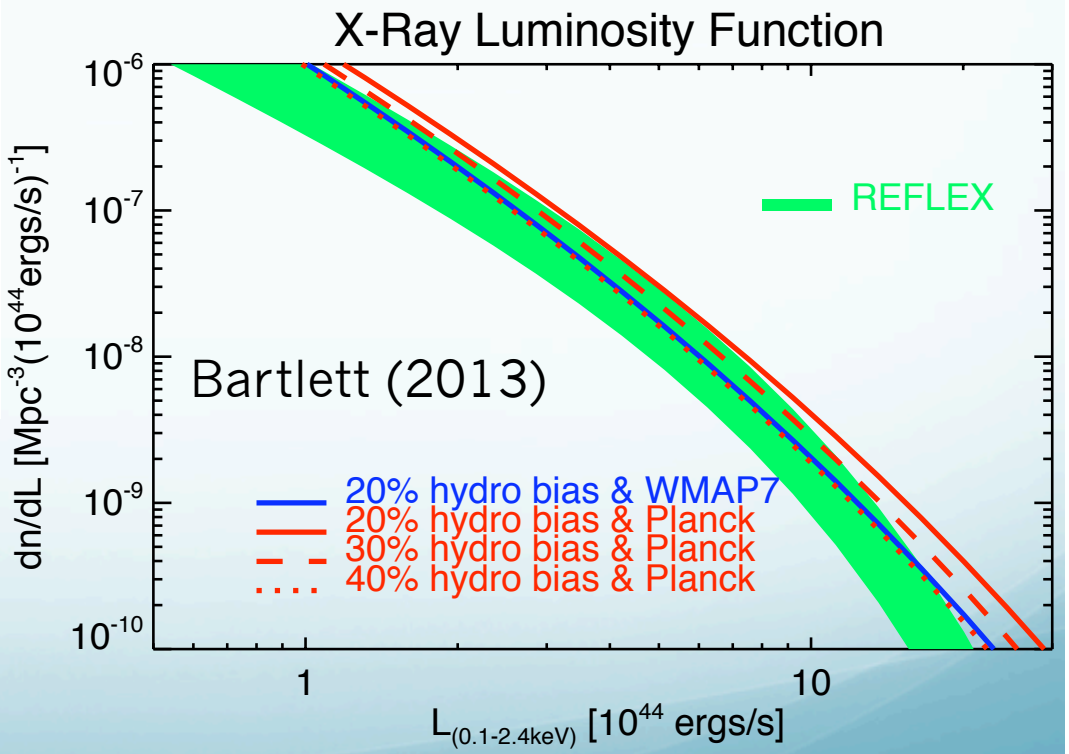
Some Consistency

Ilic, Blanchard & Douspis (2015)



Local temperature function

Planck CMB cosmology



Cluster Counts & CMB

Planck Collaboration XXIV (2015)

Data	$\sigma_8 \left(\frac{\Omega_m}{0.31}\right)^{0.3}$	Ω_m	σ_8
WtG + BAO + BBN	0.806 ± 0.032	0.34 ± 0.03	0.78 ± 0.03
CCCP + BAO + BBN **[Baseline]**	0.774 ± 0.034	0.33 ± 0.03	0.76 ± 0.03
CMBlens + BAO + BBN	0.723 ± 0.038	0.32 ± 0.03	0.71 ± 0.03
CCCP + H_0 + BBN	0.772 ± 0.034	0.31 ± 0.04	0.78 ± 0.04

Primary CMB (TT,TE,EE+lowP, LCDM):

$$\sigma_8 = 0.831 \pm 0.013$$

$$\sigma_8 \left(\frac{\Omega_{\rm m}}{0.31}\right)^{0.25} = 0.835 \pm 0.015$$

Planck Collaboration XIII (2015)

Neutrinos

Neutrino Mass

- Tension between SZ clusters & CMB
- Potential solution is non-minimal neutrino mass

$$\sum m_\nu > 0.06\,\mathrm{eV}$$

- It can lower the small-scale perturbation amplitude today relative to the base LCDM model

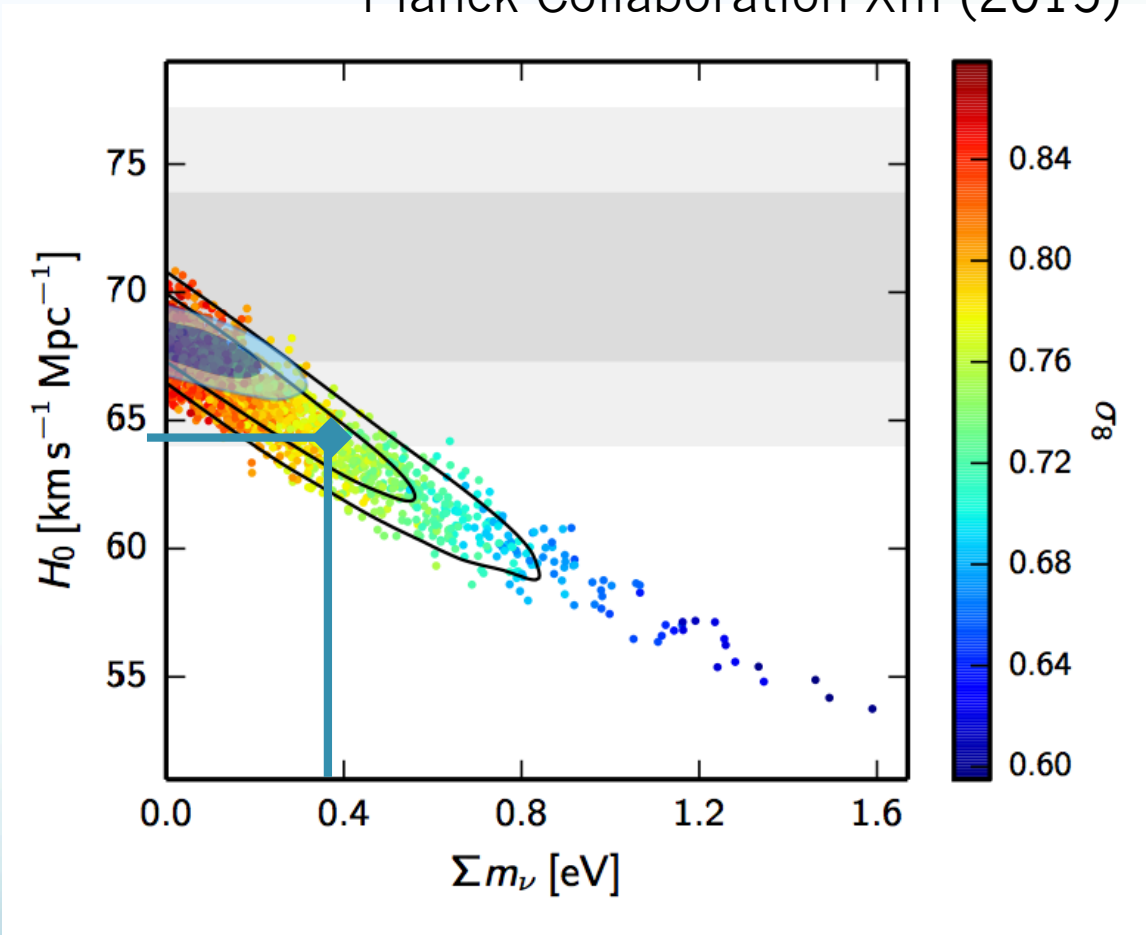
Neutrino Mass and σ_8

For CCCP central value of b:

$$\sum m_\nu \sim 0.4\,\mathrm{eV}$$

$$H_0 \sim 65\,\mathrm{kms^{-1}Mpc^{-1}}$$

Planck Collaboration XIII (2015)



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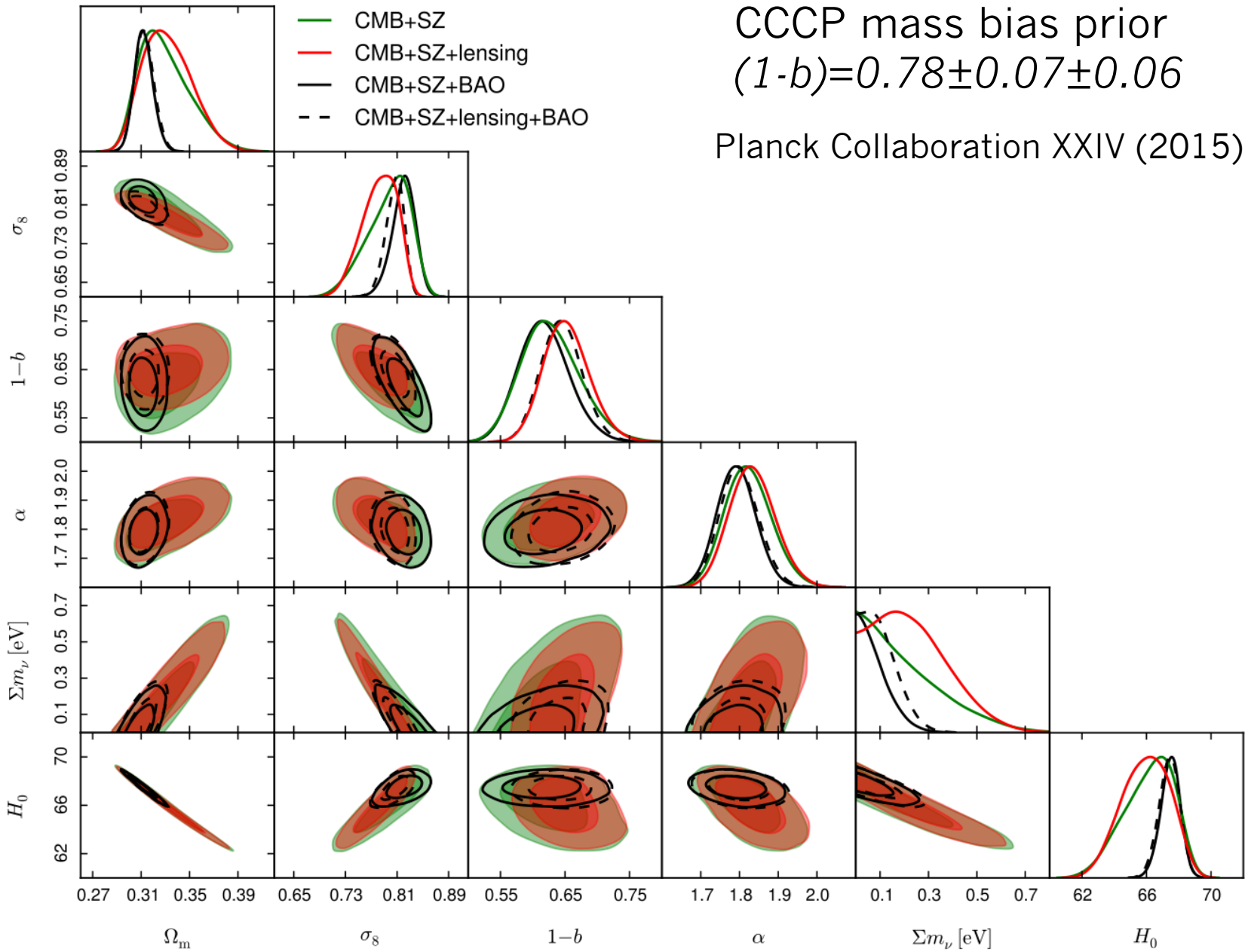
- But it also drives H_0 even lower

Joint SZ + CMB Analysis



CCCP mass bias prior
(1-b)=0.78±0.07±0.06

Planck Collaboration XXIV (2015)

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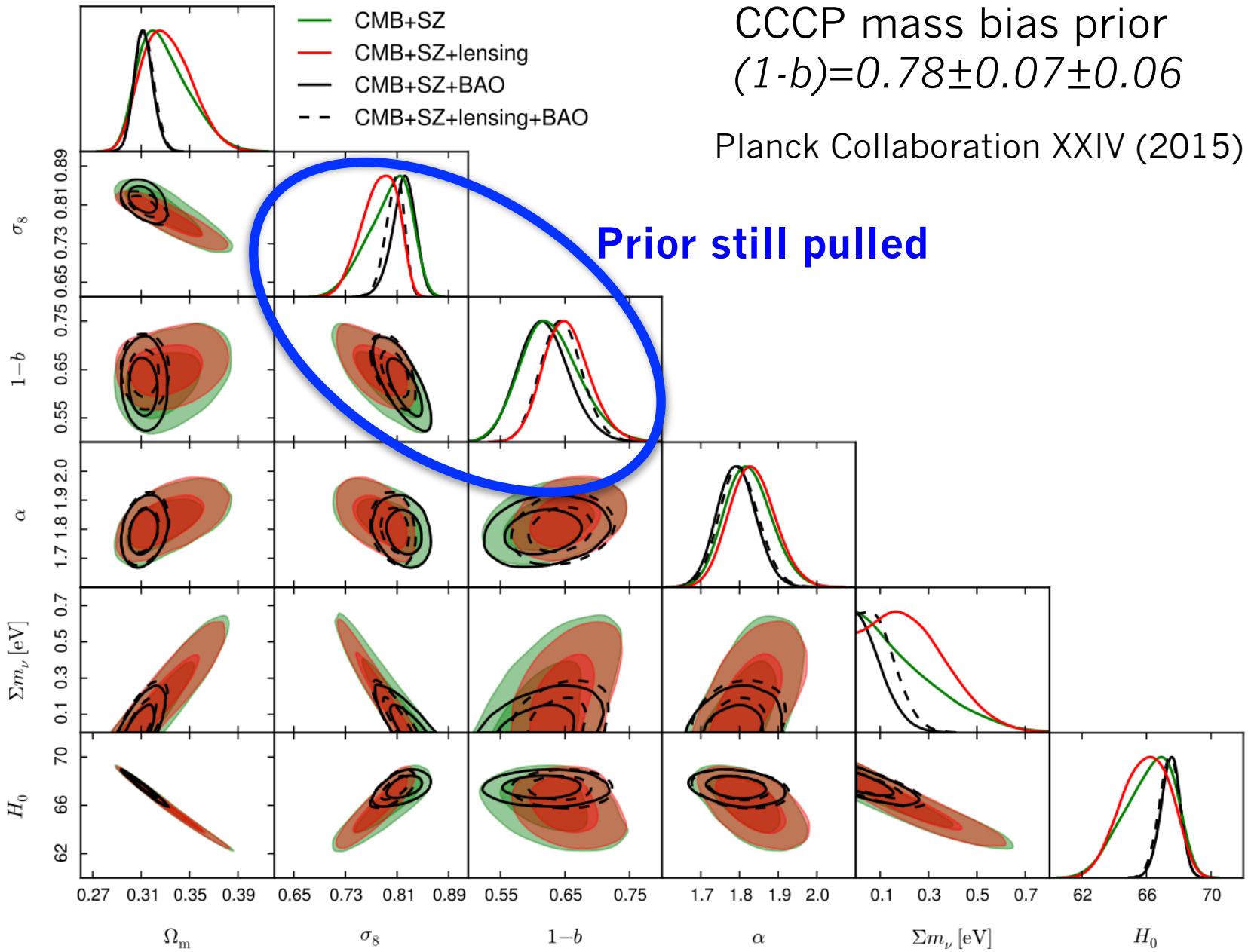

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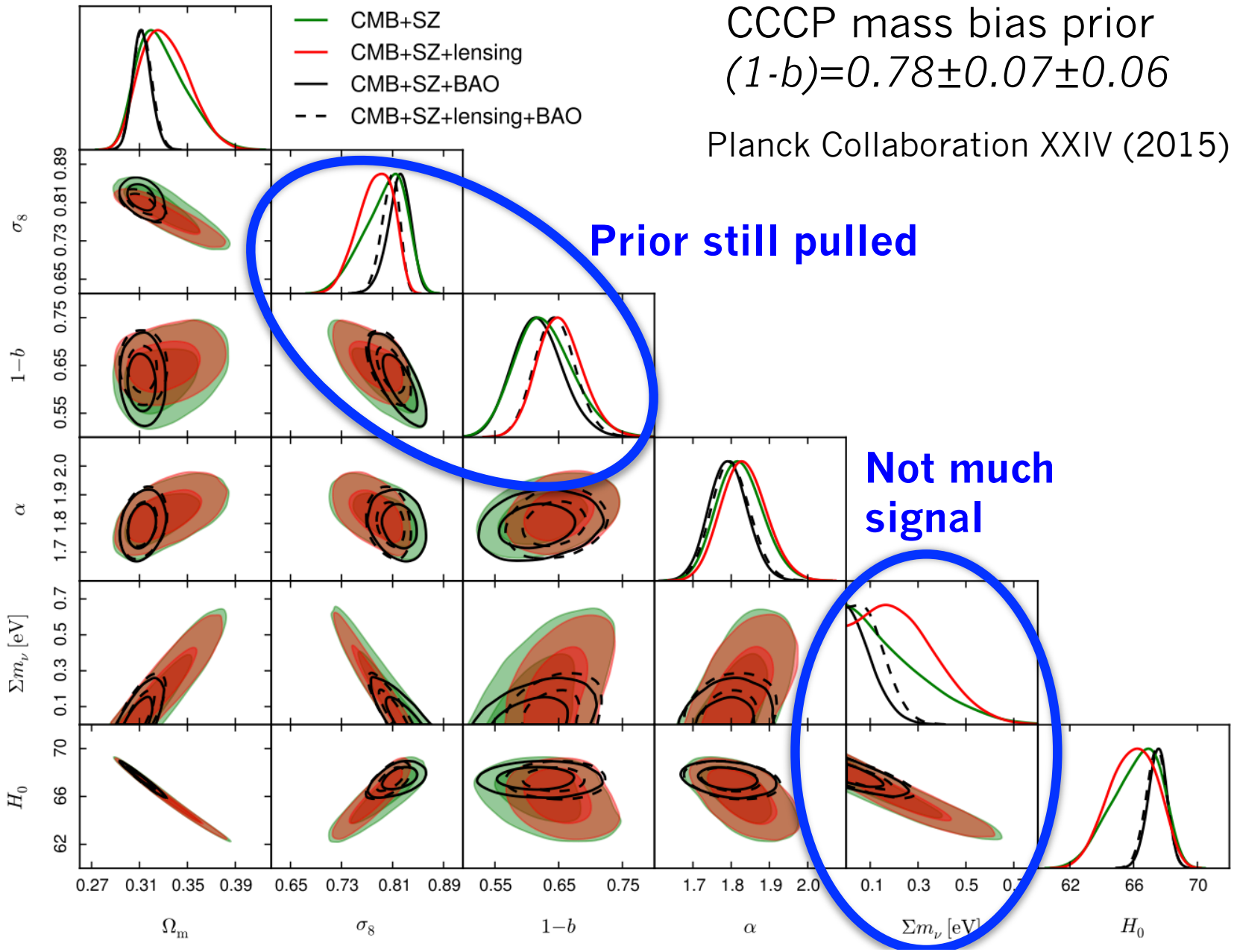

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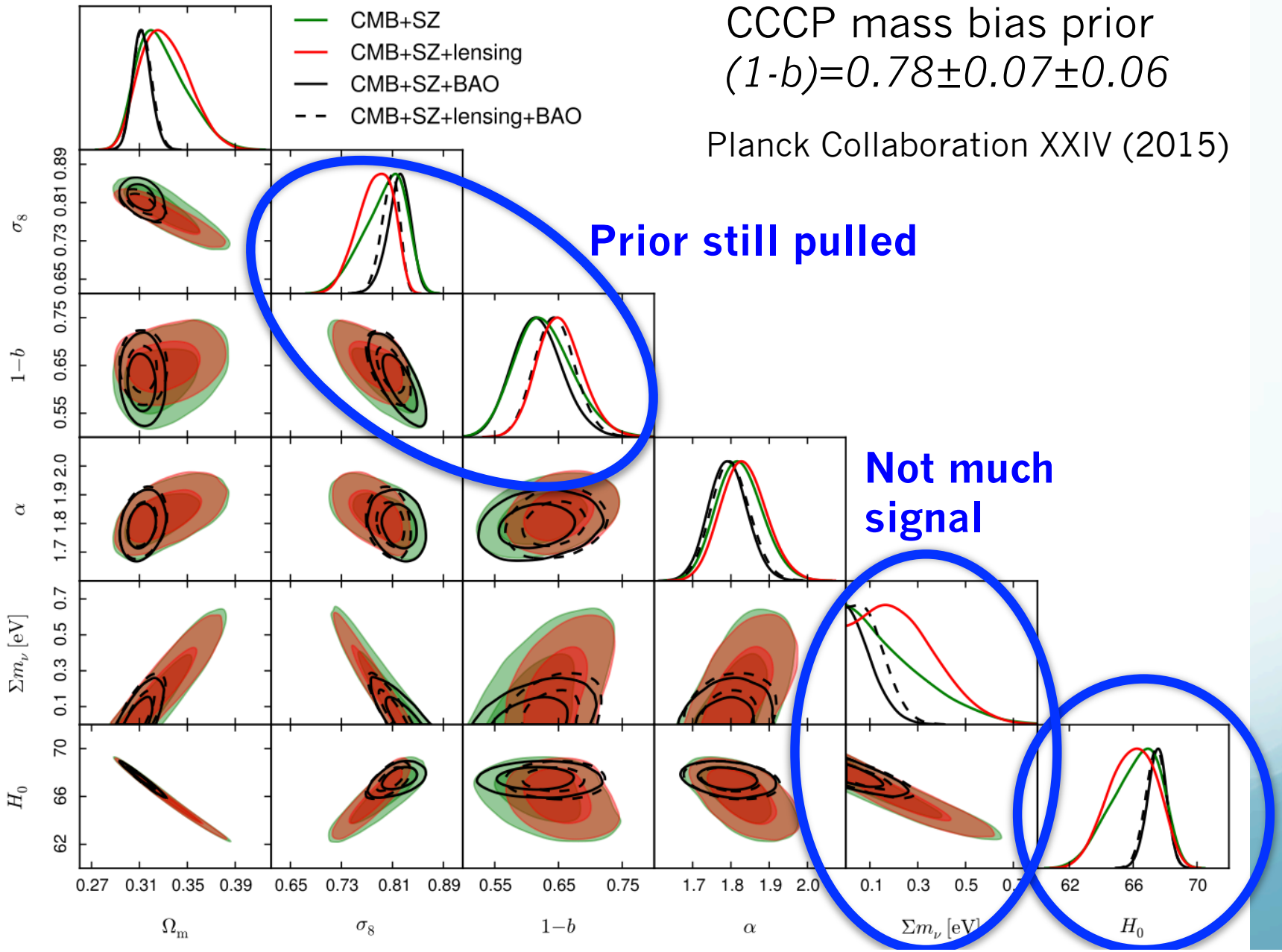

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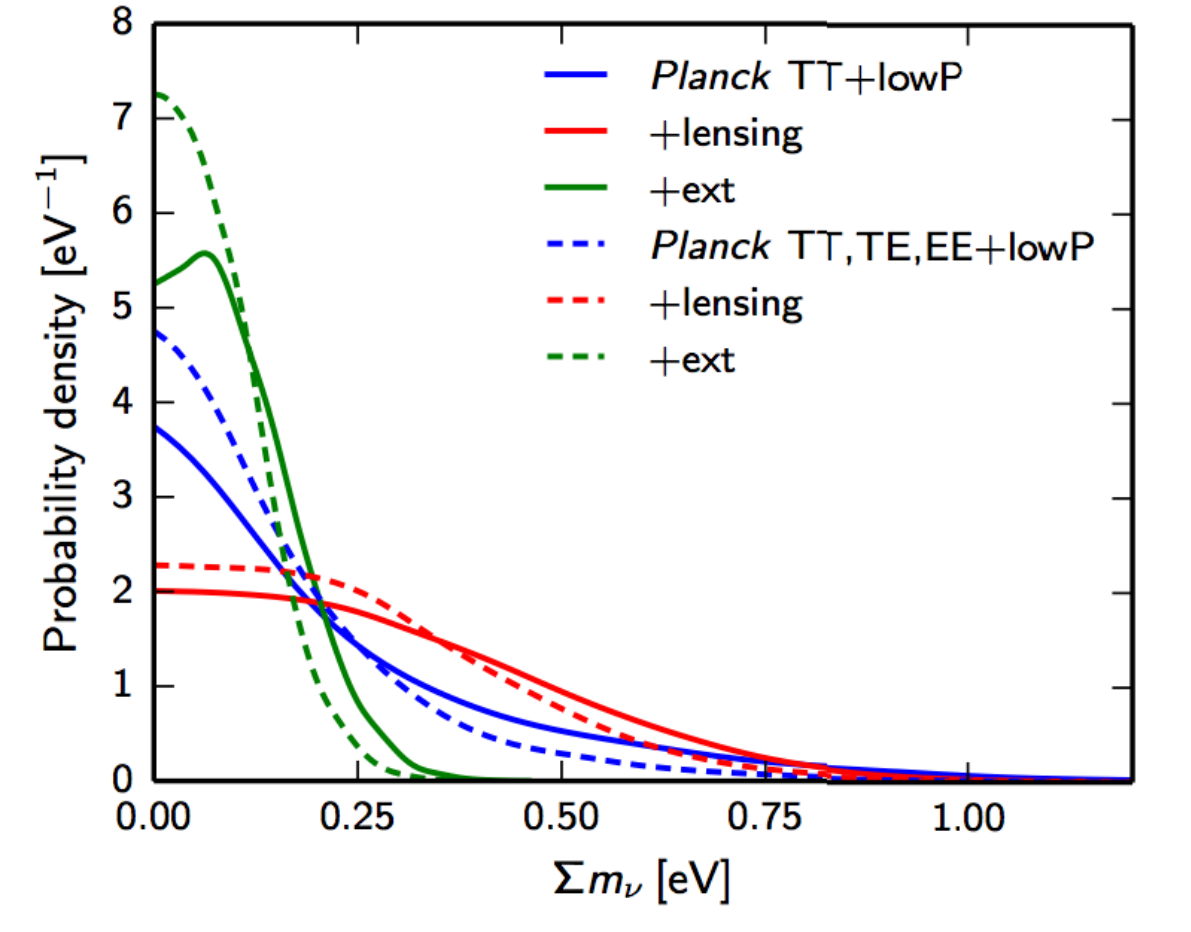
Planck Collaboration XXIV (2015)

CMB Constraints

CMB alone constrains neutrino mass:

⇒Neutrinos become non-relativistic at recombination at the larger masses

Planck Collaboration XIII (2015)



Neutrino Mass

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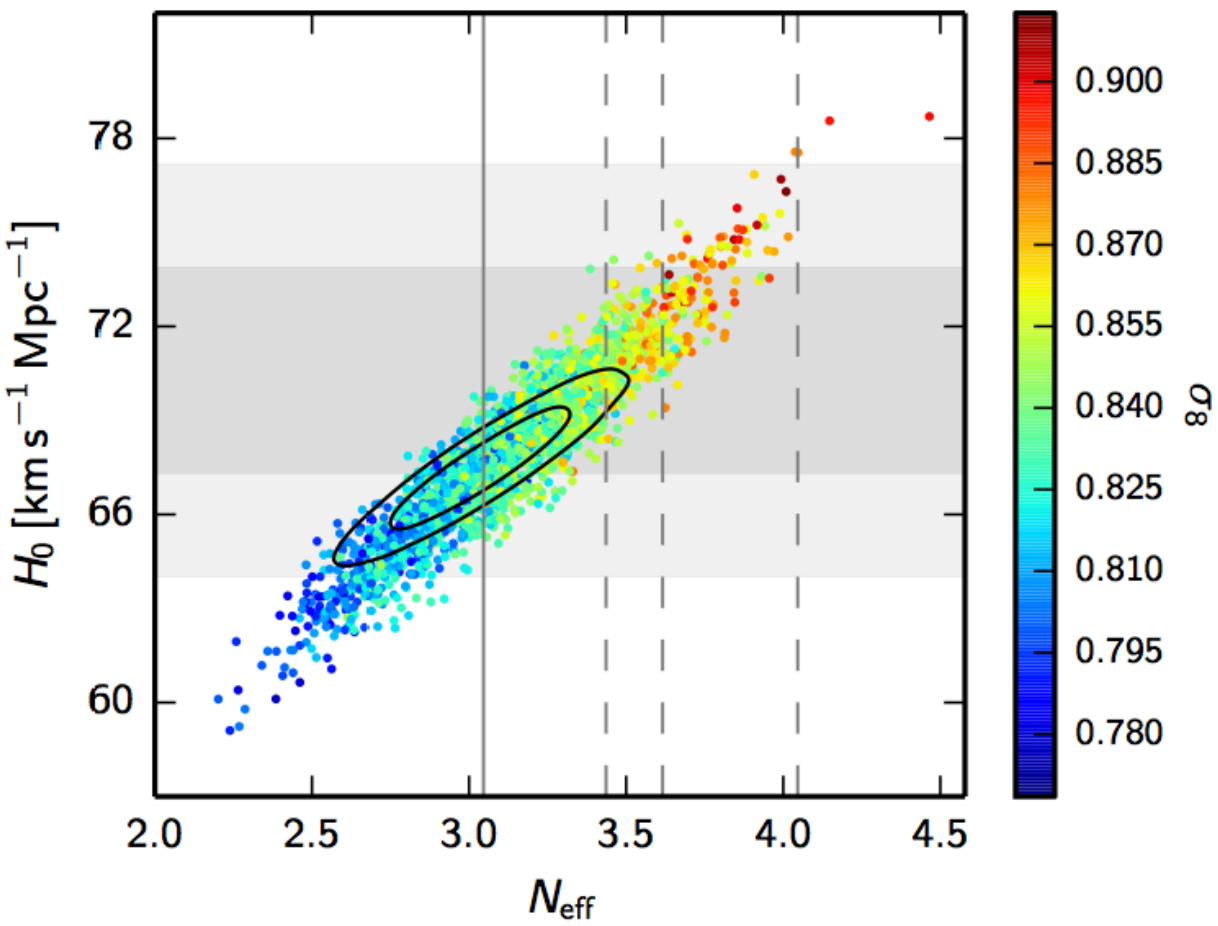
$$\sum m_\nu > 0.06\,\mathrm{eV}$$

- It can lower the small-scale perturbation amplitude today relative to the base LCDM model
- But it also drives H_0 even lower
- Tug-of-war between CMB and cluster constraints: seeks a compromise

Corollary

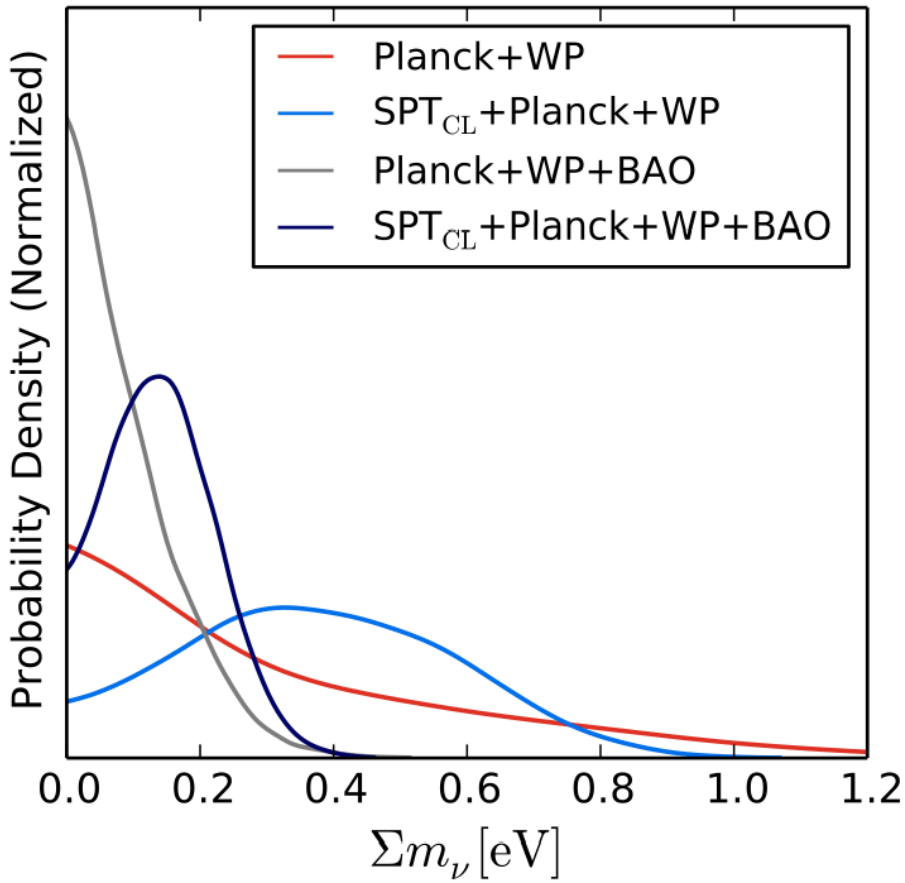
"Fixing" H_0 with N_{eff}, e.g., Reiss+ (2016) makes it worse

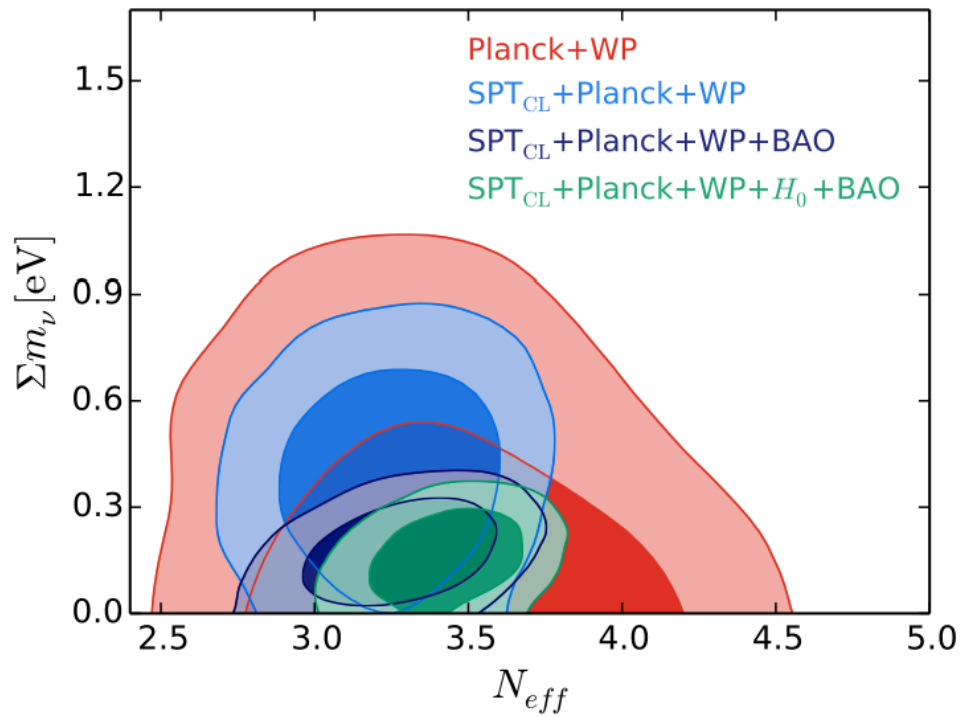
Planck Collaboration XIII (2015)



Neutrinos

SPT, Haan et al. (2016)

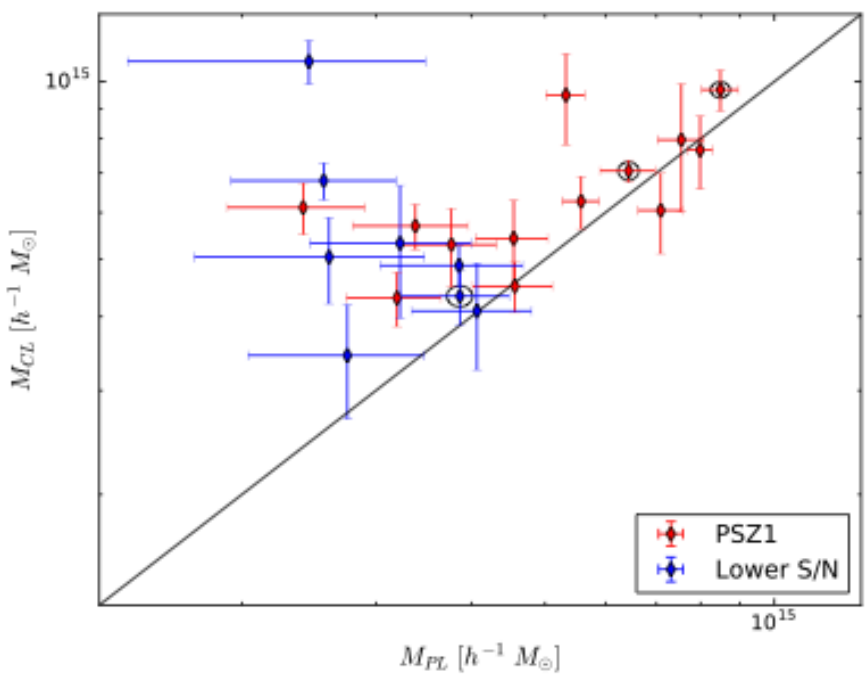


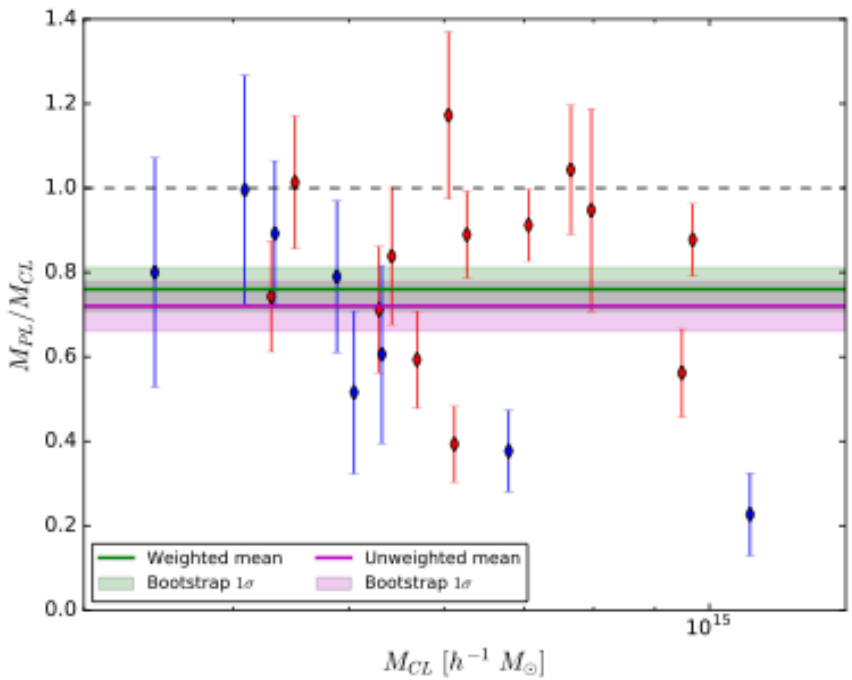


Mass Calibration

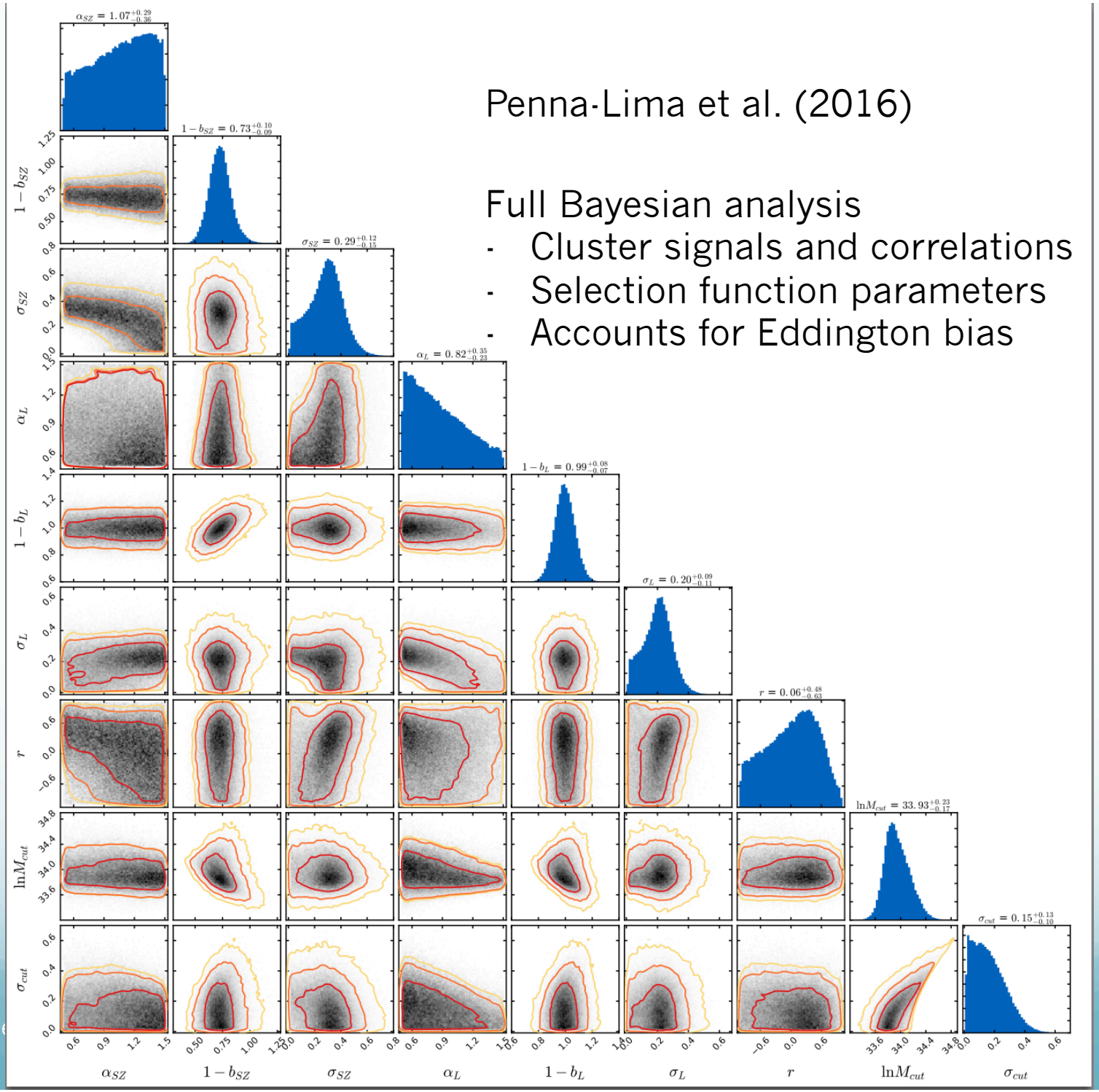
CLASH-*Planck*

Penna-Lima et al. (2016)





Extracted *Planck* SZ signal for 21 CLASH clusters.
Use CLASH strong+weak lensing masses to calibrate *Planck* cluster scale.



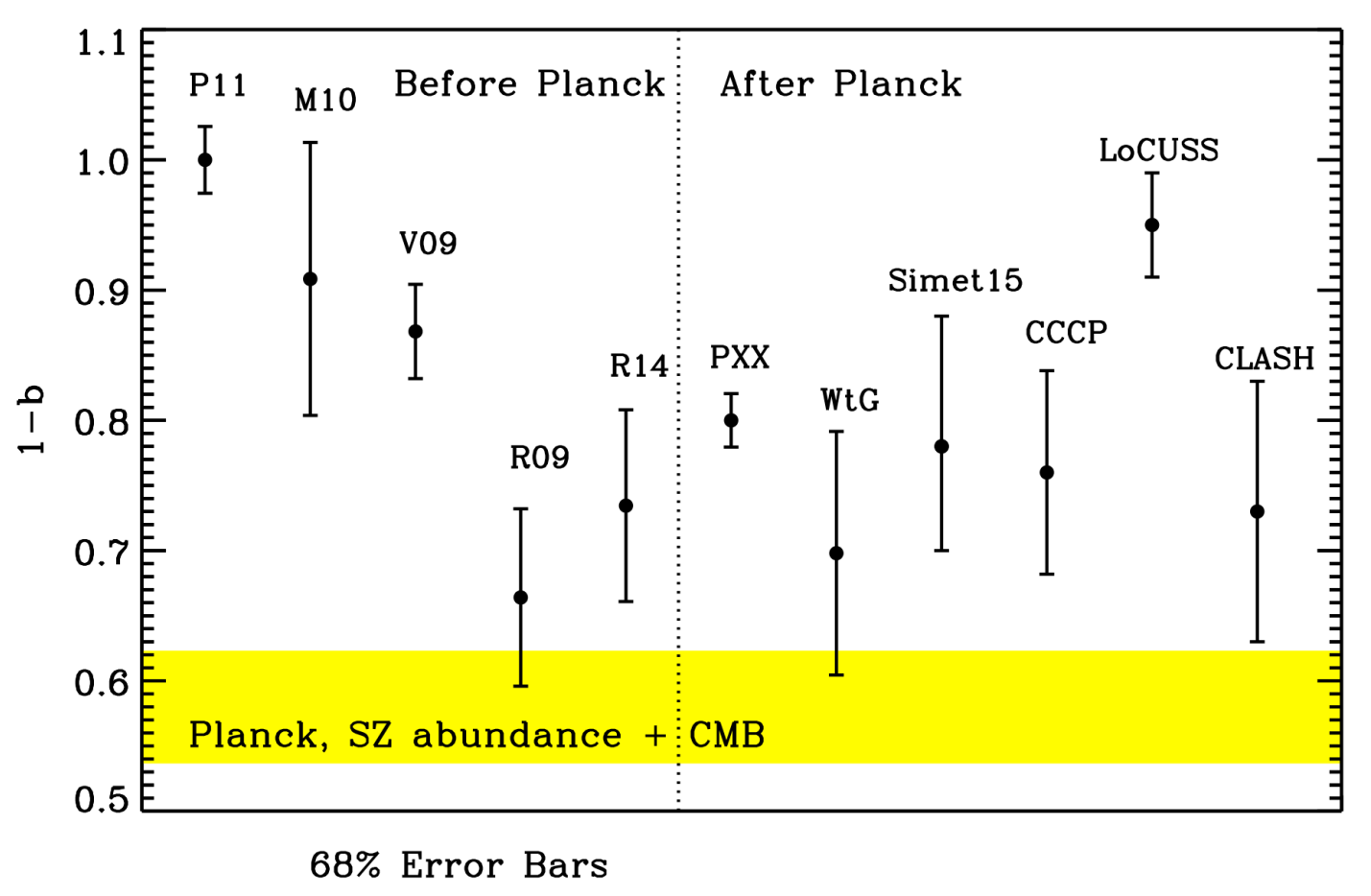
Penna-Lima et al. (2016)

Full Bayesian analysis

- Cluster signals and correlations
- Selection function parameters
- Accounts for Eddington bias

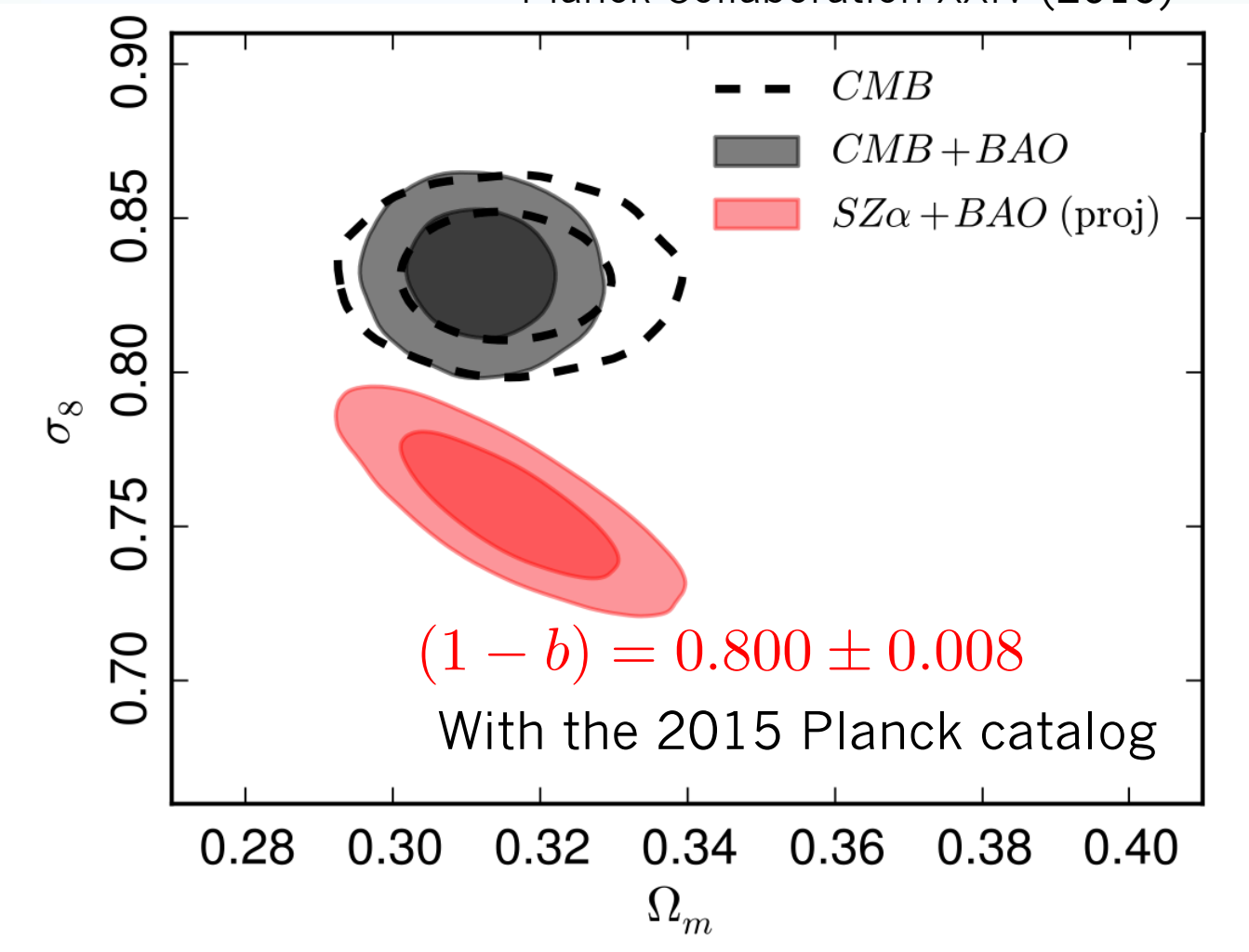
Present Situation

Penna-Lima et al. (2016)



Future Goal: 1% on Mass Bias?

Planck Collaboration XXIV (2015)

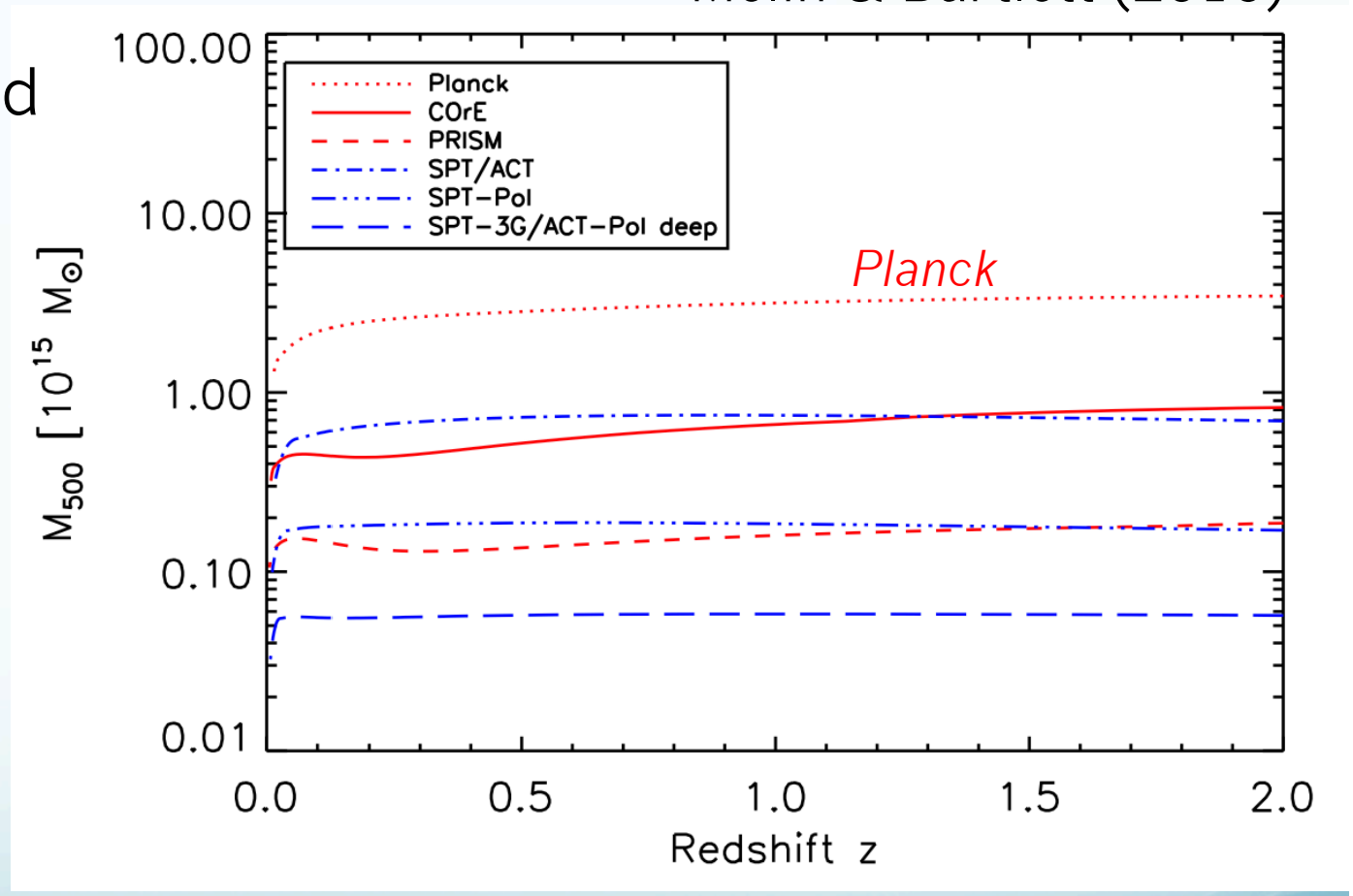


Cluster-CMB Lensing

Lensing potential reconstruction and matched filtering

Predictions for cluster mass detectable with S/N=1

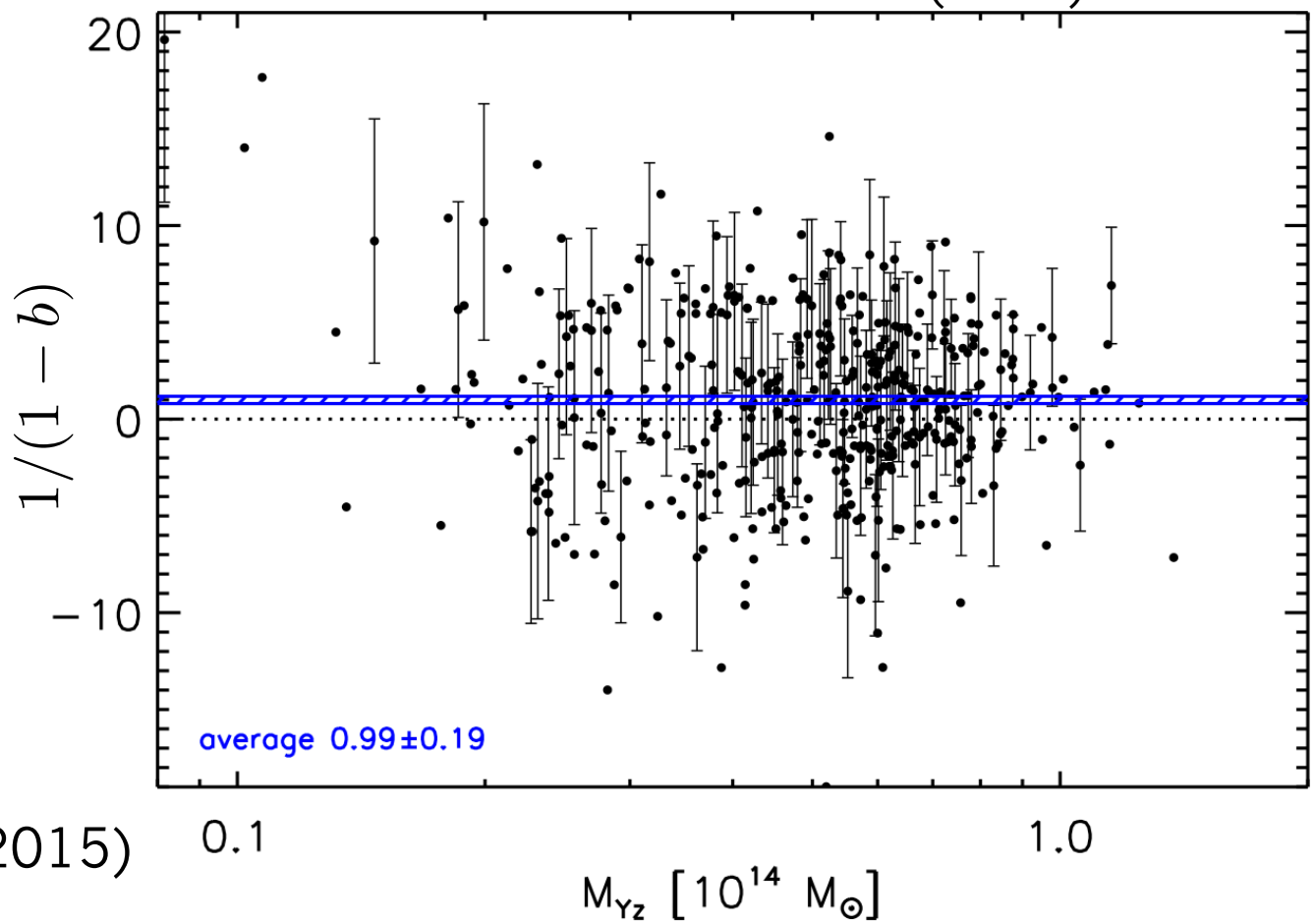
Melin & Bartlett (2015)



Cluster-CMB Lensing

439 *Planck* 2015 cosmology clusters: 5 σ measurement

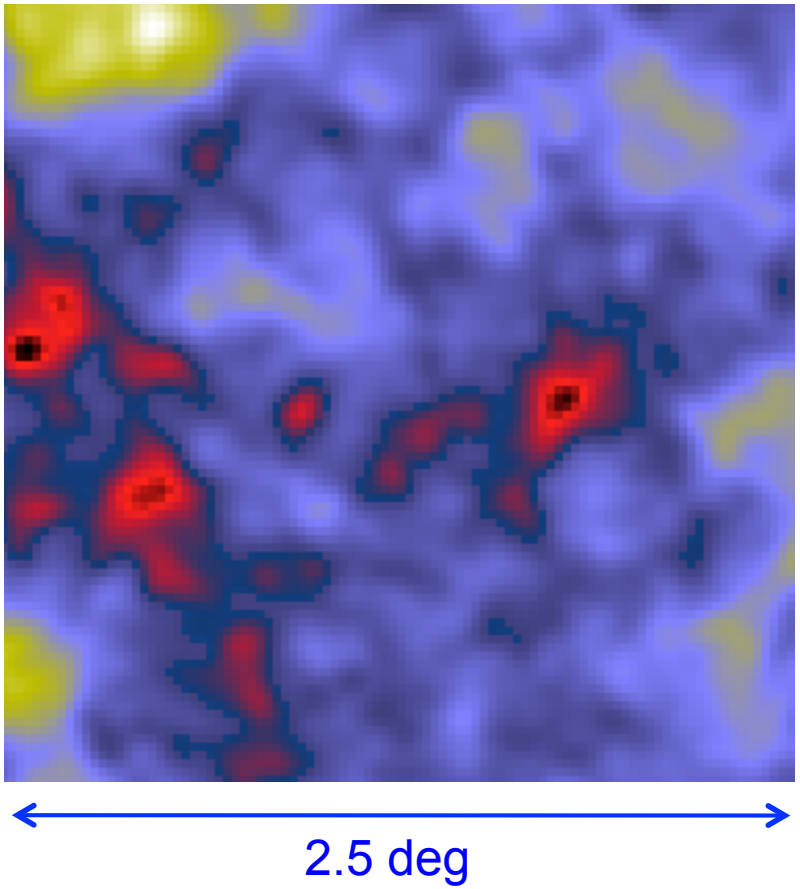
Planck Collaboration XXIV (2015)



See also:
Madhavacheril et al. (2015) (ACT)
Baxter et al. (2015) (SPT)

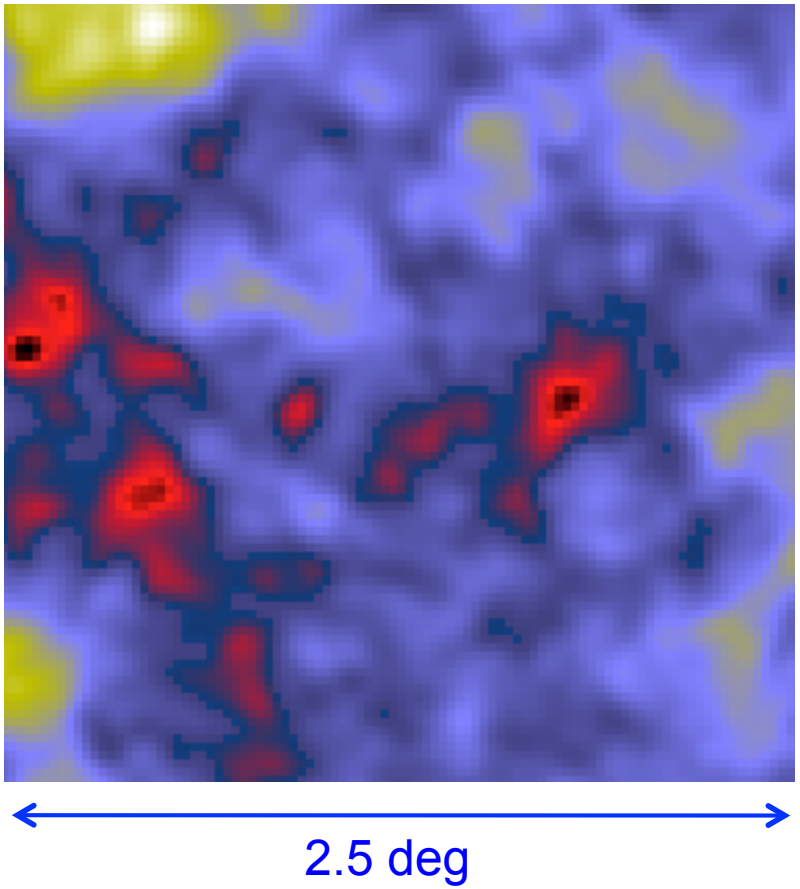
Planck Simulation of A2163

Cluster-CMB lensing with *Planck*
(Melin & Bartlett 2015)



Unlensed CMB

Planck Simulation of A2163



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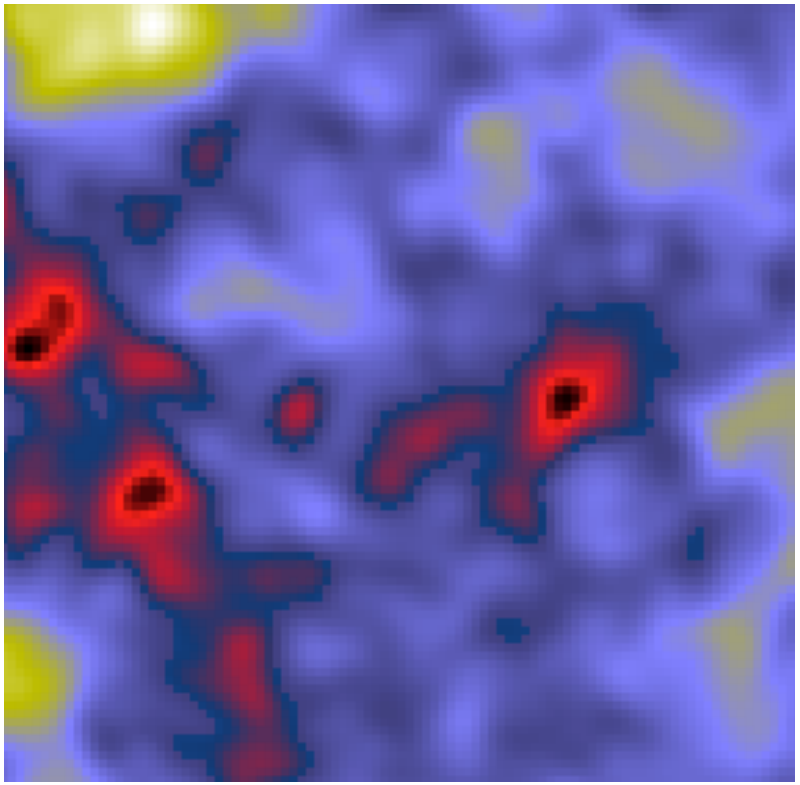
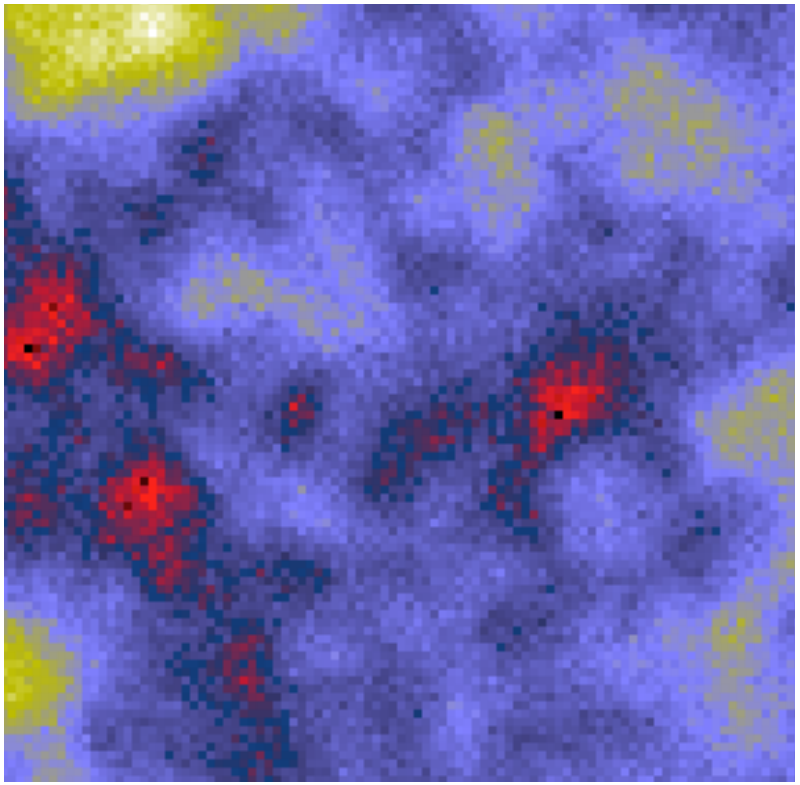


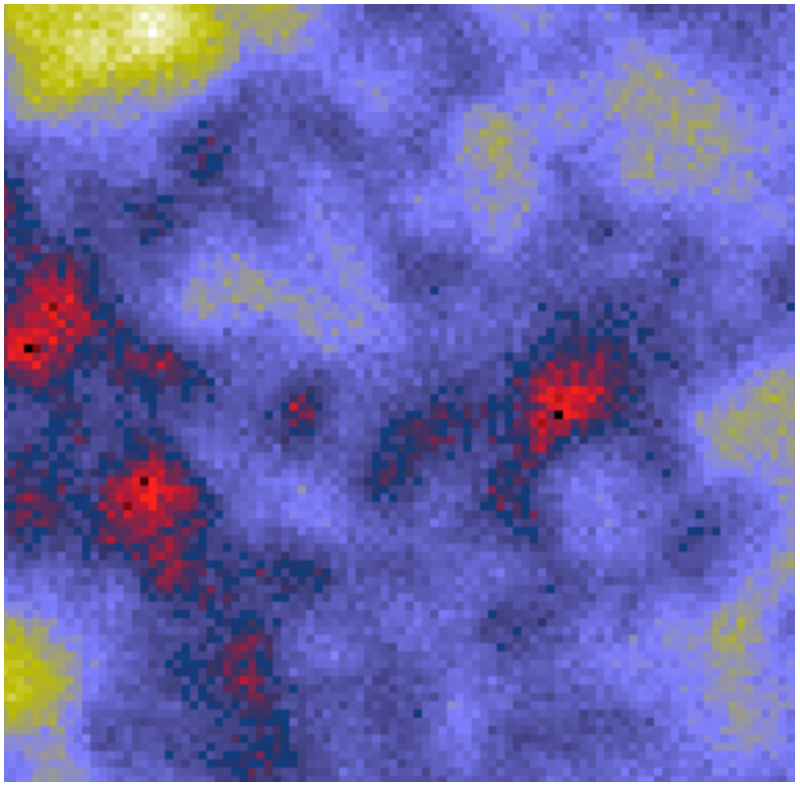
Lensed CMB
+ 5arcmin beam

Planck Simulation of A2163



Lensed CMB
+ 5arcmin beam
+ instrumental noise

Planck Simulation of A2163



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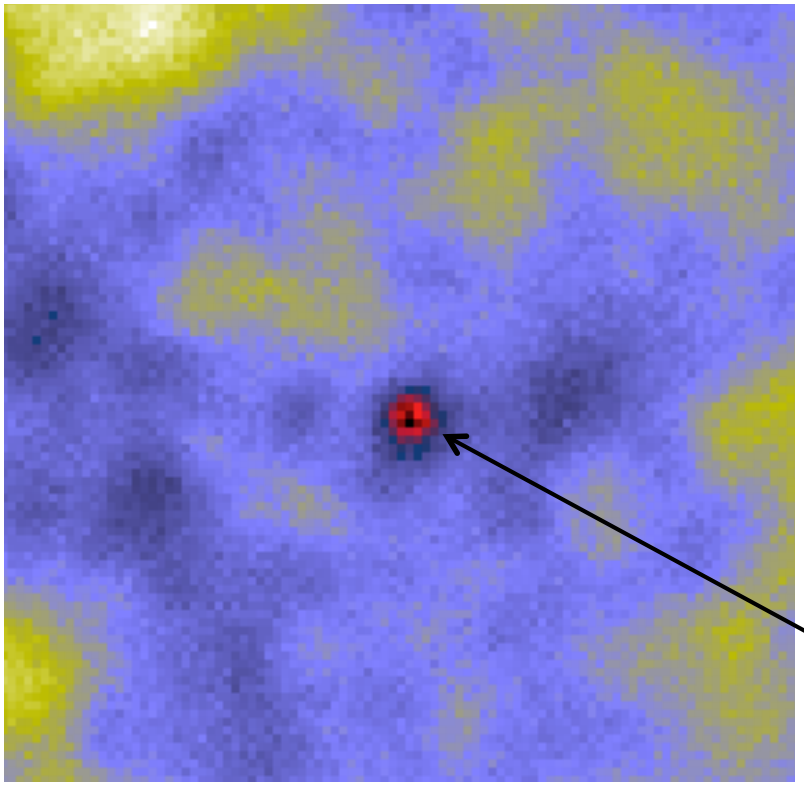
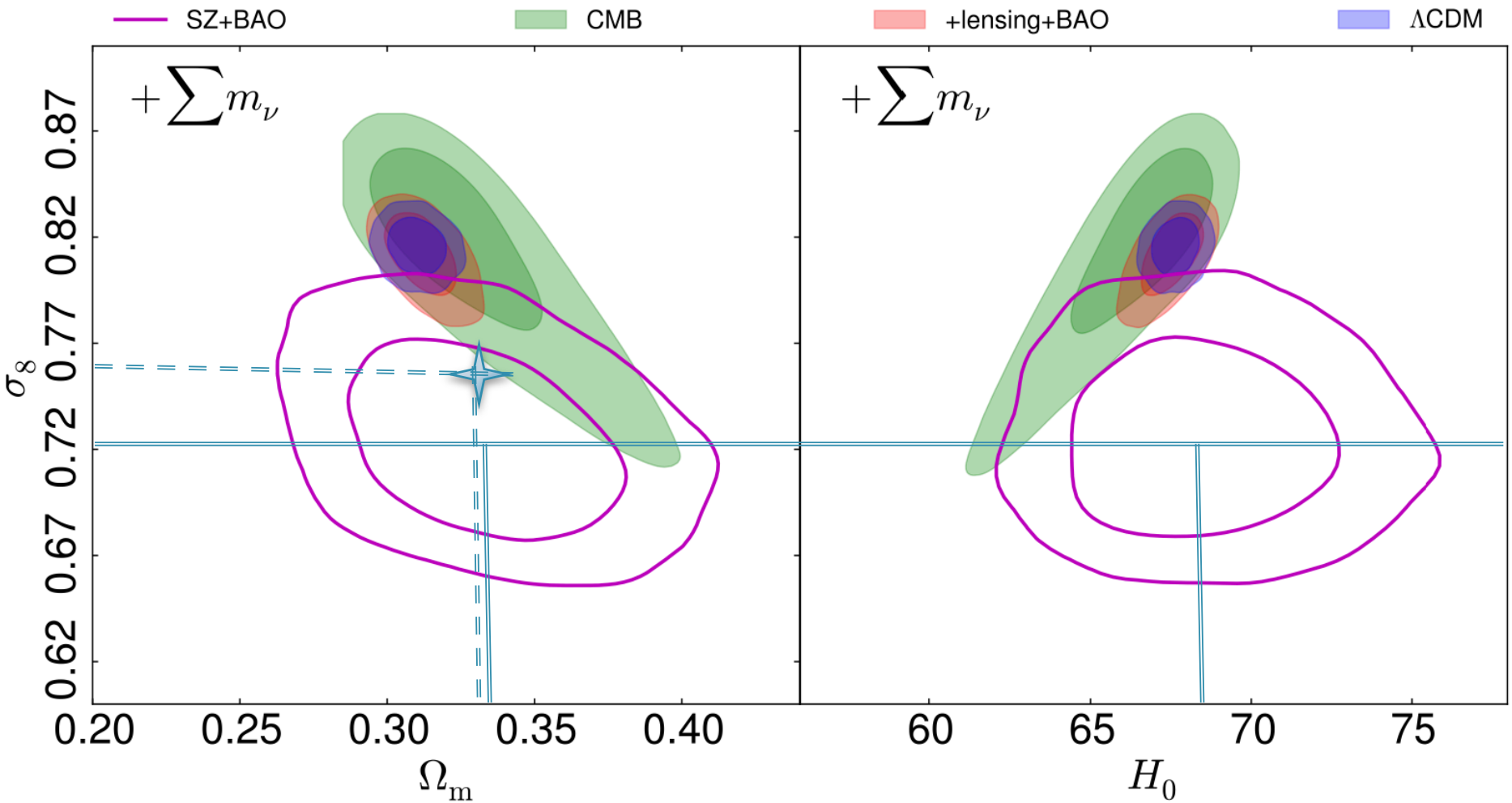


Planck observation
@ 143GHz

SZ !

Conclusions

- Tension between cluster counts and *Planck* primary CMB constraints
  - Importance depends on mass calibration: Largest source of uncertainty
  - Tension seen in some other LSS tracers
- Non-minimal neutrino mass reduces tension
  - Tug-of-war between direct CMB constraints and LSS constraints
  - Drives H_0 even lower compared to local measurements
- Mass calibration efforts are key and on-going

Planck Collaboration XXIV (2015)